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Claes Gejrot, Edmund Schjånberg

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THE SHALE OIL INDUSTRY IN SWEDEN

BY

CLAES GEJROT AND EDMUND SCHJÅNBERG (*)

SYNOPSIS. *The Swedish shale oil plant at Kvarntorp, which was built during the war, has since been largely reconstructed, extended and modernized. It is now in a position to cover its costs in full, including normal depreciations, and to render a return on the invested capital. Manufacturing costs must however be further reduced and its products more widely utilized and refined. Thus the surplus of pyrolysis gas is to be converted into ammonia, gasoline is to be refined catalytically and the ash used as building material. The problems of the purification of flue gases and the gasification of shale coke are being considered in order to open the way for a further expansion of the plant.*

RÉSUMÉ. *L'usine suédoise d'huile de schiste à Kvarntorp, construite pendant la guerre, a subi pendant ces dernières années d'importantes transformations et agrandissements et a été rationalisée, de sorte qu'il est possible déshormais de compenser intégralement les coûts, y compris les décomptes normaux et d'assurer une rémunération au capital investi. Les frais de fabrication doivent cependant être encore réduits et les produits doivent être mieux utilisés et raffinés. Ainsi, le surplus de gaz de pyrogénation doit être transformé en ammoniaque, l'essence doit être raffinée catalytiquement et le résidu doit être utilisé comme matériel de construction. On est en train d'étudier l'épuration des fumées et la gazéification du coke de schiste dans le but de créer de nouvelles possibilités d'agrandissement de l'usine.*

RIASSUNTO. *L'impianto svedese per la produzione di olio di scisto di Kvarntorp, costruito durante la guerra, è stato recentemente in gran parte ricostruito, ampliato e rimodernato. L'impianto è oggi in grado di coprire completamente i suoi costi, incluse le normali quote di ammortamento, e di consentire una remunerazione al capitale investito. I costi di lavorazione dovranno tuttavia venire ulteriormente ridotti, ed i prodotti dovranno essere raffinati e utilizzati in modo migliore. L'eccesso di gas di pirolisi sarà convertito in ammoniaca, la benzina sarà sottoposta a raffinazione catalitica, e le ceneri saranno utilizzate come materiale da costruzione. Sono attualmente allo studio i problemi della purificazione del gas di scarico e della gassificazione del coke di scisto, allo scopo di aprire la via ad una ulteriore espansione dell'impianto.*

Introduction

When the Swedish Shale Oil Co. was formed in 1941, its management was able to build on the results achieved by Sven V. Bergh, Fredrik Carlsson, G. H. Hultman, Bror Holmberg and other engineers and scientists in their many years of theoretical and experimental work to discover suitable methods of pyrolysis and processes for the conversion of crude shale oil and crude gas into marketable products.

There are two essentially different systems to choose between for the pyrolysis of shale. Firstly, there are the methods involving heating of the shale, if possible in a wholly enclosed retort without admission of air, the gaseous pyrolysis products being removed and treated separately without admixture of flue gases. Secondly, there are the methods involving the combustion of the pyrolyzed shale, the shale coke, in the retort, whereby the gases of pyrolysis and combustion are mixed and removed together.

In view of the composition of the Swedish shale, methods belonging to the former group only were initially adopted in Kvarntorp. The same applies to Ljungström's more recently

(*) Swedish Shale Oil Co. Inc., Kvarntorp, Sweden.

developed electrothermal "in situ" method and the modified Bergh retorts, i. e., the so-called Kvarntorp method.

The composition of Kvarntorp shale is as follows:

SiO_2		42-46 %	Carbon about	18 %
Al_2O_3		12.5-14 %	Hydrogen	2 %
Fe_2O_3		8-9 %	Sulphur	6-7 %
K_2O	about	4 %	Ash	72 %
Na_2O		<1 %	Heat value about 2000 kcal/kg	
MgO		<1 %	Pyrolysis according to Fischer gives 5.8 % oil, 86 % coke, 3.4 % water and 4.8 % gas	
CaO	about	1 %		

From the start the plant was equipped with a sulphur recovery plant for refining the gaseous pyrolysis products by removing their hydrogen sulphide content of roughly 20 %, and for the production of superior quality sulphur in quantities sufficient to meet the requirements particularly of the Swedish sulphite mills during the emergency caused by the war.

Modernization and Expansion of the Plant

In 1945 it was decided that the shale oil industry should be regarded as a normal peacetime undertaking, capable of covering its overheads and current expenses without State-aid and, of course, as far as possible returning interest on the invested capital. A rather considerable additional capital was required for reconstruction and extension of the plant and for covering losses during the years of transition. Since the Swedish shale oil deposits were considered adequate to justify this capital expenditure, a programme was worked out for the reconstruction of the Kvarntorp plant, based on experience gained up to that time.

Of the total heat contents of the shale, about 29 percent is recovered as condensable oil, 18.5 percent as gas, and the remainder as coke with a heat value of about 1200 kcal/kg. The coke calories are of a magnitude that makes it essential to utilize them. In the Bergh oven the coke was burnt with a great surplus of air. The capacity of the oven was determined by the rate at which the coke could be burnt without the risk of sintering the ash (sintering point 900-950°C). In the two other methods the heat value of the coke was not utilized. Intensive research and experimental work resulted in an entirely new combustion method based on the La Mont principle. The shale coke was burnt in tall shafts in which cooling pipes were placed. The latter were connected to a La Mont circulation system operating at 25 atm. pressure. The same idea was also adopted for the coke combustion in the Bergh ovens, whereby the capacity limitation due to the sintering risk was overcome.

The installation of the coke combustion plant and the increase in capacity of the Bergh oven provided the requisite conditions for advancing towards the above-mentioned goal, that is, a system of production which would prove economically feasible under normal marketing procedures. The realization of this goal naturally presupposes a return of the full market value for oil, gas and steam.

The oil must be fractionated and the crude-gasoline and kerosene must be refined. Processes, especially suitable to the particular properties of the shale oil, were worked out, and the products obtained have successfully competed with imported oils. The non-condensable gas contains, among other things, a mixture of hydrogen sulphide, hydrocarbons, hydrogen and nitrogen. The analysis is as follows:

H_2S	19.0	vol.- %	C_2H_6	5.8	vol.- %
CO_2	8.0	"	C_2H_4	0.7	"
CO	0.6	"	C_3H_8	2.0	"
O_2	0.8	"	C_3H_6	1.2	"
H_2	16.5	"	C_4-hydrocarbons	1.8	"
N_2	25.0	"	$>C_4$	1.5	"
CH_4	17.1	"			

The importance of sulphur production from hydrogen sulphide is manifest, and the capacity of the sulphur plant was therefore increased from the start. The output today is about 28,000 tons per annum, or roughly half of Sweden's total consumption. The quantity of gas remaining after removal of the hydrogen sulphide represents about 11,000 m³ (STP)/h with a heat value of about 6,000 kcal/m/(STP). The gas contains about 100 g light gasoline and 125 g C_3 and C_4 hydrocarbons per m³ (STP). These products are recovered in a separate plant. The former product is refined together with the crude gasoline. The latter product is sold under the trade name of Gasol (liquefied petroleum gas) to a quantity of 12,000 tons per annum. The gas remaining after the recovery of Gasol is used as fuel in the shale oil plant and for the Örebro Municipal Gas supply.

The steam produced in the Kvarntorp retorts and the coke combustion plant is used

partly as process steam and partly for power production. The power produced is used as process power in the plant and the surplus power corresponds to the basic load which must always be applied to the Ljungström electrothermal field. The Ljungström process today contributes about 20 percent of the company's total production of oil and gas.

The shale beds at the same time yield large quantities of bituminous limestone, which is separated, burnt and sold as agricultural and industrial lime.

The annual production capacity is shown in Fig. 1.

Economy

Reorganization measures have, of course, been aimed not only at increasing production but above all at reducing manufacturing costs per unit. It would take too long to give an account of what has been planned and achieved in this respect. The result may be best understood from the number of days' work per 1000 kronor of sales value recalculated at equivalent prices in the two years under comparison. If the sales value is recalculated at the 1951-52 price level, the number of days' work fell from 21.1 in 1946-47 to 10.1 in 1953-54. If this result of reorganization is instead expressed as costs per 1000 kronor of sales, also recalculated at the 1951-52 price level, it is found that the costs have fallen by more than 40 percent.

The company's last definitive balance sheet shows that costs excluding depreciation and interest on capital loans are about 3 percent less than income. The income, on the other hand, is 12 percent lower than the figure required for full coverage of normal depreciation. A quite different picture is seen, however, if the figures are recalculated at the 1948 level of costs and prices, which show a surplus of about 10 % after normal depreciation of plant. The change in the cost level has in fact meant a percentual increase in expenditure by 57 %, while the average prices of all products only lie 12 % above the 1948 level. This is because the company purchases no raw materials, no fuel, and only limited quantities of electrical energy. This fact is, of course, very important, particularly in the event of war, but it also means that the company has been severely hit by the rise in wages and costs of materials that has taken place since 1950.

Future Plans

If Kvarntorp had concentrated on oil production alone, the company would have incurred such losses, without even taking depreciation into account, that operation under normal peace-time conditions would have been economically impossible. The utilization of the by-products of coke and non-condensable gas, however, has made it possible for the company to realize its goal of fully covering its costs including normal depreciation and return on capital investment. This state of affairs will not be attained, however, until manufacturing costs have been still further lowered and the present products have been further refined in order to fetch a higher market price. The gas must be used for other purposes than fuel, and some use must be found for the ash.

The Pyrolysis Gas

The pyrolysis gas which remains after extraction of the hydrogen sulphide and "Gasol", and which attains a quantity of about 11,000 m³ (STP)/h, has the following approximate composition:

H_2	25 vol.-%	CH_4	25 vol.-%
N_2	35 "	C_2-hydrocarbons	10 "
CO_2, CO and O_2	5 "		

Of the above quantity, 6000 m³ (STP) are required as process fuel in the plant, while the remainder can be released for other purposes. A plant is under construction in which this latter quantity, after thermal cracking of the hydrocarbons with water vapour, will be converted into a gas composed of 75 percent hydrogen and 25 percent nitrogen, which will then be used for ammonia synthesis by conventional methods. The annual production of ammonia will be 22,000 tons with a sales value many times as great as would have been obtained if it had been used for the production of electrical energy in a steam power plant. The quantity of gas is too small to make its transport by pipeline to other consumers a feasible proposition.

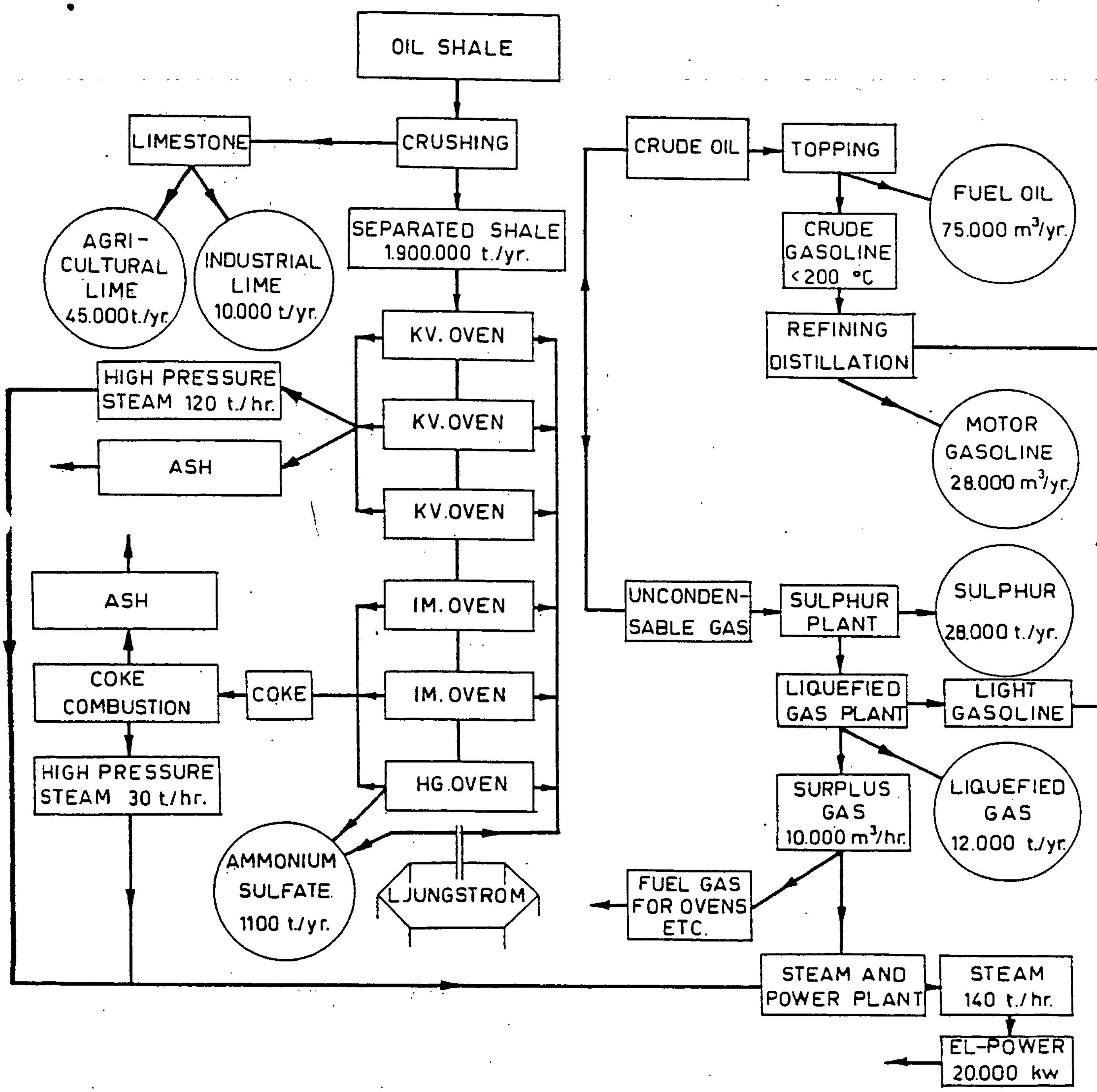

Fig. 1. Annual Production Capacity of Kvarntorp Plant

Oil

The crude oil is subjected to topping, yielding crude gasoline with a final boiling point of 200°C and a heavy oil. The latter is sold as fuel oil, but pilot plant experiments have proved that a fully satisfactory transformer oil and an acceptable diesel oil can be produced by hydrogenation or extraction with furfural. This applies particularly to Ljungström oil. Another method of refining the heavy oil is, for example, wholly to cokify it to gas, gasoline and coke; the company has already done some work on this process and will continue its efforts still further.

Gasoline

The crude gasoline is at present refined with concentrated sulphuric acid, which produces a very good quality of gasoline with a high octane number, but unfortunately the losses are considerable. The demand for higher octane numbers is growing year by year, and other refining methods have therefore been investigated. A new catalytic method, including a low pressure hydrogenation in the presence of a selective catalyst with subsequent reforming, has proved very suitable. The obtainable yield is entirely dependent on the degree of reforming, the losses being a gas with a high " Gasol " content. The gasoline obtained is stable with a high induction time and good lead sensitivity.

Ash

Shale ash is not an inert material, but possesses certain hydraulic properties. Attempts have therefore been made to use it for bricks and as a cement extender. Bricks are produced from finely ground ash, lime, water and small quantities of certain chemicals. This mixture is poured into moulds, vibrated or compressed and autoclaved with steam. The bricks meet all the demands made on ordinary burnt brick, and in certain respects is in fact superior. Attempts to produce hollow bricks are also proceeding. If ordinary cement is mixed with 20 percent fine-ground shale ash, its strength after 28 days storage is increased. Also in other respects the ash-mixed cement has better characteristics than unmixed cement. Concrete, too, made from this ash-mixed cement, fulfils all the demands normally made on concrete. Final tests of frost resistance are under way. The ash may also find a use in the building of roads and railway embankments. The recovery of the small quantities of molybdenum and vanadium and of the larger quantities of aluminium and potassium which are present in the shale ash would hardly be an economic proposition.

Flue Gases

The combustion of the shale coke yields ash and steam and, in addition, large quantities of flue gases with a sulphur dioxide content of about 0.7 percent. Despite this comparatively low content, it has been found that damage has been done to surrounding vegetation owing to the immense quantity of flue gases.

Two methods of purifying the flue gases of sulphur dioxide are being investigated. One is by washing them with an aqueous solution of ammonium sulphite, whereby ammonium bisulphite is formed which, after desorption with steam, gives off sulphur dioxide. The regenerated ammonium sulphite solution is recirculated to the washing tower, while the sulphur dioxide is compressed and liquified. The undesirable oxidation to sulphate is prevented by the addition of an inhibitor and by working at a low temperature.

The other method of purifying the flue gases is adsorption on some active form of carbon or silica gel. During the carbon adsorption a part of the dioxide always oxidizes into trioxide which is then reduced to dioxide by the carbon during desorption. The recovered dioxide is partly mixed with carbon dioxide. As a consumption of carbon takes place, a cheap active carbon must be used. Lignite coke has been found to possess good adsorption and desorption properties. Silica gel has proved an excellent adsorption agent, provided that the flue gas is dry. An organic product in aqueous solution that is stable to oxidation will also be tried as an adsorption agent.

The essential condition for the utilization of these methods is that the content of solid particles in the flue gas is less than 50 mg/m^3 (STP). A purification to this degree can be easily arranged by means of an electrofilter.

Flue gases that have been purified by any of these methods may be released into the chimney without inconvenience.

Under present conditions some 500,000 m^3 (STP) of flue gases are obtained per hour. This would mean an annual production of up to 80,000 tons of liquid sulphur dioxide, a product

in great demand by the Swedish sulphite pulp industry. Of this quantity 40 percent could be converted with the hydrogen sulphide of the pyrolysis gas into elemental sulphur in the existing Claus plants, and the production of sulphur would increase by 15,000 tons a year.

The oils, sulphur, "Gasol" and other products, recovered at present in the plant, are of highest quality. When the above-mentioned processes, which are all well in line with the present capacity of the plant, have been realized, some of the products will be further refined to more valuable products and other new by-products obtained. The flue gases will be cleaned and the ash will be utilized as far as is considered possible today. The surplus of pyrolysis gas will be converted into ammonia. In addition, there is a certain production of agricultural and industrial lime and of electric energy. Even if a further rationalization of the plant should bring about a possible 20 percent increase in capacity, this would hardly affect the plans that have been touched upon here.

Further Extension of the Plant

The question of extending the present shale oil plant has been discussed, but this will not be possible until the problem of purifying the flue gases has been solved or until new methods of pyrolysis have been found. The most likely solution is the gasification instead of combustion of the shale coke. This would produce a gas with a heat value dependent on the method of gasification. Using oxygen and water vapour as gasifying agents with the coke in a fluidized bed method, a gas with about 2,500 kcal/m³ (STP) should be obtainable. Investigations with this end in view have been started and will probably be speeded up. The heat value of the gas obtained can be further raised by mixing with sulphur-free and "Gasol-free" pyrolysis gas, or by some after-treatment such as methanization to permit the gas to be economically transported in high pressure pipelines to large consumer points. If the plant is extended, the quantities of gas and "Gasol" produced would be so great as probably to enable petrochemicals to be manufactured on a profitable basis. The present size of the plant is inadequate for this purpose.

The development outlined here is by no means impracticable, indeed it is a highly probable one. If it is followed, Swedish shale will achieve a position in Swedish industry – and particularly in the Swedish fuel economy – which its resources deserve.

This paper was presented on June 13th, 1955 by C. J. GEJROT and E. SCHJANBERG.

Discussion

O. SCHAECHTER (*Israel Mining Industries, Laboratories – Haifa, IL*). Anybody who has been working in this field has been very much impressed by the efforts of the Swedish Shale Oil Industry to maintain their industry on an economic basis. I would like to ask if in the picture they have considered the possible utilization of uranium. It is known that many shales contain a certain amount of uranium and I ask if anything of this kind has been considered for the Swedish shale. I would like also to ask two more questions. One is: what is the content of carbon in the spent shale which leaves finally the plant? And the other question, again connected with the economic picture: do the Swedish shale oil engineers expect their plant to pay ultimately on the basis of being exempt from the usual taxes on other fuels, or do they think they could make it, even paying those taxes?

C. J. GEJROT *replies.* There is a special company founded in Sweden, the Swedish Atomic Energy Company, that handles the work, that is to find out if it is possible to produce uranium in small quantities. It is therefore impossible for me to-day to give you more detailed information in this respect, and the only thing I can do is to tell you that the percentage of uranium in our shale is about 150 to 200 grammes per ton, that is a very low content. These figures are published, so I can refer to them now. In South Africa there is about the same content in the raw material that they use for the same purpose.

Now there is the question if the Swedish shale oil plant can make competition to other imported products without any state aid at all. That is of course what we expect from our plant in a couple of years. To-day we pay all current expenses, and in the future we don't reckon on any state aid at all. We have no

duties on the products we produce in the Swedish Shale Oil Plant in Sweden. When we have fulfilled our intentions, the shale oil plant will be an absolute peacetime undertaking, which fulfils all the requirements that can possibly be demanded from such an industry. Finally, I would mention that the percentage of organic carbon in the spent shale is about 3 %.

E. J. GOHR (*Esso Research and Engineering Co. – New York, N. Y. USA*). I would first like to compliment Mr. Gejrot and the Swedish Shale Oil Company on the very important work they have done on the utilization of oil shale. I would like to ask if Mr. Gejrot can supply any information, first about the amount of nitrogen in the Swedish Shale, and second, to what level nitrogen is reduced in the hydrogenation operation. And my third question is: is there any treatment given to the raw shale oil before it is hydrogenated, is it coked before hydrogenation, for example ?

My fourth question is: is there any information that the gentlemen from Swedish Shale Oil Company may give us on the operating conditions for the hydrogenation, in other words, what is the pressure, is the catalyst regenerated, and information of that kind ?

C. J. GEJROT *replies*. I think it is better if Mr. Schjånberg answers this question; he may indicate the nitrogen content of the shale itself: I think there is a very low nitrogen content in the shale itself. As regards the high nitrogen content you may have noticed in the analysis of the gas, this high figure was due to some air coming into the retorting from the outside. Then comes the question about hydrogenation of the crude gasoline. We have planned a new method to take care of the gasoline treatment; but up to now we only treat gasoline with sulphuric acid in order to get a good finished product.

E. SCHJÅNBERG *replies*. The nitrogen content of the shale is only about 0,1-0,2 %. We have only made a few investigations about the hydrogenation of the gasoline; we work at about 20 to 30 atm. and with a selective catalyst, which can be regenerated. We are working this problem with a German Company.